For the circuit above:

- What is the Differential Gain, $G_d = V_o/(V_B - V_A)$?

- What is the Common-mode Gain, $G_{cm} = V_o/(\frac{1}{2}(V_B + V_A))$?

- What is the Common-mode Rejection Ratio (CMRR)?

All op amps are ideal with $V_{CC} = 15$ V and $V_{CC} = -15$ V.

- What is the Differential Gain, $G_d = V_o/(V_B - V_A)$?

\[
V_o = \left( \frac{R_1 + R_2}{R_3 + R_4} \right) \left( \frac{R_3}{R_2} \right) V_B - \left( \frac{R_1}{R_2} \right) V_B
\]

\[
V_o = \left( \frac{22 + 1.501}{22 + 1.5} \right) \left( \frac{22}{1.501} \right) V_B - \left( \frac{22}{1.501} \right) V_B = 14.6673 V_B - 14.6569 V_A
\]

Set $V_B = -V_A = 1$ V, $V_d = V_B - V_A = 2$ V.

$G_d = V_o/V_d = (14.6673(1) - 14.6569(-1))/2 = 14.6621$

- What is the Common-mode Gain, $G_{cm} = V_o/(\frac{1}{2}(V_B + V_A))$?

Set $V_B = V_A = 1$ V, $V_{cm} = \frac{1}{2}(V_B + V_A) = 1$ V.

$G_{cm} = V_o/V_d = |14.6673(1) - 14.6569(1)|/1 = 0.0104$

- What is the Common-mode Rejection Ratio (CMRR)?

$CMRR = 20 \log_{10} \frac{14.6621}{0.0104} = 62.98$
For the circuit above:

- Sketch $V_o$ as a function of time.
- What is $V_x - V_y$ at $t = 45$ ms?

All op amps are ideal with $V_{CC} = 15$ V and $V_{CC} = -15$ V.

\[
V_o = \left(1 + \frac{2R_A}{R_G}\right) \left(\frac{R_1}{R_2}\right) (V_B - V_A)
\]

\[
V_o = \left(1 + \frac{2 \times 54}{2.9}\right) \left(\frac{41}{2.5}\right) (V_B - V_A) = 627.2 (V_B - V_A)
\]

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$V_A$ (mV)</th>
<th>$V_B$ (mV)</th>
<th>$V_o(V) = 627.2(V_B - V_A)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2.0</td>
<td>4.1</td>
<td>1.317</td>
</tr>
<tr>
<td>15</td>
<td>2.5</td>
<td>4.1</td>
<td>1.004</td>
</tr>
<tr>
<td>25</td>
<td>2.0</td>
<td>4.1</td>
<td>1.317</td>
</tr>
<tr>
<td>35</td>
<td>2.0</td>
<td>6.5</td>
<td>2.822</td>
</tr>
<tr>
<td>45</td>
<td>2.0</td>
<td>4.1</td>
<td>1.317</td>
</tr>
</tbody>
</table>

- What is $V_x - V_y$ at $t = 45$ ms?

\[
V_x - V_y = \left(1 + \frac{2R_A}{R_G}\right) (V_B - V_A)
\]

\[
V_x - V_y = 38.24 (V_B - V_A) = 38.24 (4.1 \text{ mV} - 2.0 \text{ mV}) = 0.080 \text{ V}
\]
For the input, $V_i$, below, sketch the output, $V_o$, on the same graph. Indicate voltage levels and the times of any transitions. (The op amp is ideal with the indicated $V_{CC}$ and $V_{EE}$ values).

Non-inverting amplifier:
Gain: $G = 1 + R_1/R_2 = 1 + 44/2.5 = 18.60$

Ideally, output would swing from $-37.20 \text{ V}$ (at $t = 0 \text{ ms}$) to $37.20 \text{ V}$ (at $t = 20 \text{ ms}$).
However, output is limited to $\pm 10 \text{ V}$.
Slope is $2 \times 37.20/20 = 3.720 \text{ V/ms}$.
So starting at $V=0$, the limit of $10 \text{ V}$ is reached in
$\Delta t = 10 \text{ V}/3.720 \text{ V/ms} = 2.688 \text{ ms}$

Thus:

<table>
<thead>
<tr>
<th>$t$ (ms)</th>
<th>$t$ (ms)</th>
<th>$V_o$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 − 2.688</td>
<td>7.31</td>
<td>−10</td>
</tr>
<tr>
<td>10 + 2.688</td>
<td>12.69</td>
<td>+10</td>
</tr>
<tr>
<td>30 − 2.688</td>
<td>27.31</td>
<td>+10</td>
</tr>
<tr>
<td>30 + 2.688</td>
<td>32.69</td>
<td>−10</td>
</tr>
</tbody>
</table>